CHAPTER 4

FUNDAMENTAL CONCEPTS OF A RELIABILITY-CENTERED MAINTENANCE PROGRAM

4-1. Objectives of RCM

This chapter provides a discussion of the two primary objectives of RCM: Ensure safety through preventive maintenance actions, and, when safety is not a concern, preserve functionality in the most economical manner.

4-2. Applicability of preventive maintenance

a. *Effectiveness.* PM can be effective only when there is a quantitative indication of an impending functional failure or indication of a hidden failure. That is, if reduced resistance to failure can be detected (potential failure) and there is a consistent or predictable interval between potential failure and functional failure, then PM is applicable. Condition monitoring has long been used to monitor operating parameters that have been shown to be dependable predictors of an impending failure. Preventive maintenance (PM) is effective if a potential failure condition is definable or there is a quantitative indication of an impending failure. PM is generally effective only for items that wearout. It has no benefit for items that have a purely random pattern of failure (i.e., failures are exponentially distributed and the failure rate is constant – see appendix B for a discussion of statistical distributions). Consequently, we rarely, if ever, use a PM action for electronics, since electronics exhibit a random pattern of failures. Mechanical items, on the other hand, usually have a limited useful period of life and then begin to wearout.

b. *Economic viability.* The costs incurred with any PM being considered for an item must be less than for running the item to failure. The failure may have operational or non-operational consequences. The costs to be included in such a comparison for these two failure consequences are Operational and Non-operational.

(1) *Operational.* The cost of repair is defined in (2) following. The operational cost is defined as the indirect economic loss as a result of failure plus the direct cost of repair. An example of an operational cost is the revenue lost by an airline when a flight must be canceled and passengers booked another airline. For military organizations where profit is not an objective, an operational cost might be the cost of a second flight or mission. Sometimes, it may be difficult for a military organization to quantify an operational cost in terms of dollars and a subjective evaluation may be needed.

(2) *Non-operational.* The non-operational cost is defined as the direct cost of repair. The direct cost of repair is the cost of labor, spare parts, and any other direct costs incurred as a result of repairing the failure (by removing and replacing the failed item or performing in-place repair of the item).

c. *Preservation of function.* The purpose of RCM is not to prevent failures but to preserve functions. Many maintenance people who are unfamiliar with RCM initially find this idea difficult to accept. As was discussed in paragraph 1-4, for many years prior to and following World War II, the "modern" view within the maintenance community was that every effort should be made to prevent all failures. Preventing failure was the focus of every maintenance technician. But products became increasingly complex and maintenance costs increased both in absolute terms and as a percentage of a product's total life cycle costs. It was soon clear that preventing all failures was technically and economically impractical. Instead, attention was turned to preserving all of the essential functions of a product. This shift from preventing failures to preserving function was fundamental to the development of the RCM approach to defining a maintenance program.

4-3. Failure

For RCM purposes, three types of failures are defined: functional, evident, and hidden.

a. Types of failures.

(1) *Functional failure.* A functional failure is one in which a function of the item is lost. A functional failure directly affects the mission of the system. To be able to determine that a functional failure has occurred, the required function(s) must be fully understood. As part of a Failure Modes and Effects Analysis (FMEA), all functions have been defined. This definition can be very complex for products that have varying levels of performance (e.g., full, degraded, and loss of function).

(2) *Evident failures.* When the loss of a function can be observed or is made evident to the operator, the failure is said to be evident. In the latter case, dials or displays, audible or visual alarms, or other forms of instrumentation alert the operator to the failure.

(3) *Hidden failures.* A hidden failure is a functional failure of an item that has occurred, has not affected performance of the end system, and is not evident to the operator, but will cause a functional failure of the end system if another item fails. In other words, because of redundancy or the nature of the item's function in the system, no single-point failure of the end system has occurred. If, on the other hand, multiple failures occur, then the system will fail to perform its function. A simple example is the system shown in figure 4-1. Either of the two redundant items, A and B, can perform a critical function. Redundancy was used because the function is critical and a single point failure was unacceptable. If either item A or B can fail without the knowledge of the operator, it is considered a hidden failure. The system would now be subject to a single point failure (i.e., the function can be lost by one more failure – the failure of the other redundant component). Hidden failures must be found by maintenance personnel.

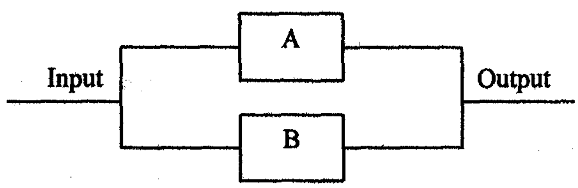

Figure 4-1. Block diagram of a simple redundant system.

b. *Failure consequences.* A basic objective of the RCM analysis is to make decisions regarding the selection of a maintenance action for a specific functional failure of a specific item based on the consequence of the failure. Three categories of failure consequences are generally used. They are safety, operational, and economic.

(1) *Safety.* If a functional failure directly has an adverse affect on operating safety, the failure effect is categorized as Safety. The functional failure must cause the effect by itself and not in combination with other failures. That is, the failure must be a single-point failure. (Note that a hidden failure for which no preventive maintenance is effective and which, in combination with another failure, would adversely affect safety must be treated as a safety-related failure. The methodology is designed to address this situation).

(2) *Operational.* When the failure does not adversely affect safety but prevents the end system from completing a mission, the failure is categorized as an Operational failure. For many end systems, operational failure results in loss of revenue. In other cases, a critical objective cannot be met. See table 4-1 for examples.

(a) An adverse effect on safety means that the result of the failure is extremely serious or catastrophic. Results can include property damage, injury to operators or other personnel, death, or some combination of these.

(b) In some industries, this category is expanded to include failures that result in a federal statute being violated. An industry such as the petroleum or power industry often includes failures that would result in violations of the Environmental Protection Act. Other industries may include failures with other effects in this category.

Table 4-1. Examples of effects of operational failures

End System	Effect of Operational Failure
Airliner	Airline must cancel flight and either send passengers to another airline or add a flight. In either case, revenue is adversely affected.
Manufacturing equipment	Production must be halted until repairs are made adversely affecting sales. Some orders may be canceled because delivery dates cannot be met (unless no other sources can provide the product to the customers – in that case, loss of customer confidence may result affecting future sales).
Military aircraft	Prolonged or lost conflict, inability to respond to a political crisis in a timely manner, or exposure to a period of vulnerability.
Financial information system	Loss of revenue due to an inability to make timely investments, penalties due to late payments, etc.
C4ISR Facility	Facility can not provide necessary electrical power to support an assigned mission.

(3) *Economic.* When a functional failure does not adversely affect safety and does not adversely affect operations, then the failure is said to have an Economic effect. The only penalty of such a failure is the cost to repair the failure.

4-4. Reliability modeling and analysis

The following is a brief discussion of reliability modeling in general and the GO method, used for facilities such as C4ISR facilities. For an in-depth discussion, see TM 5-698-1.

a. *Reliability modeling.* To evaluate the reliability characteristics of a system, and its constituent elements, a model is needed. Table 4-2 lists some of the methods most often used to model reliability.

Table 4-2. Methods for modeling reliability

Method	Comment
Reliability Block Diagram	A method of modeling that uses series and parallel connections to represent a system. The series connections represent opportunities for single point failures. Parallel connections represent redundancy.
Fault Tree	A top-down analysis useful for identifying multiple failure conditions, and the effect of human operation and maintenance on system failure. Useful for developing trouble-shooting procedures.
Single Line Diagram	Used for GO analysis (see paragraph 4-4b).

(1) *Reliability block diagram (RBD).* Figure 4-2 is an example of an RBD. The system consists of five subsystems. Subsystems B, D, and E are all instances where one failure can cause the system to fail; i.e., each of these subsystems is like the link in a chain and if one fails, the "chain" fails. Subsystems A and C have redundancy. Subsystem A will fail to perform its system function only if both item 1 and 1A fail. Likewise, subsystem C will fail to perform its system function only if both item 3 and 3A fail. If the reliabilities of items 1, 1A, 2, 3, 3A, 4, and 5 are known, the reliability of the system can be calculated (see TM5-698-1).

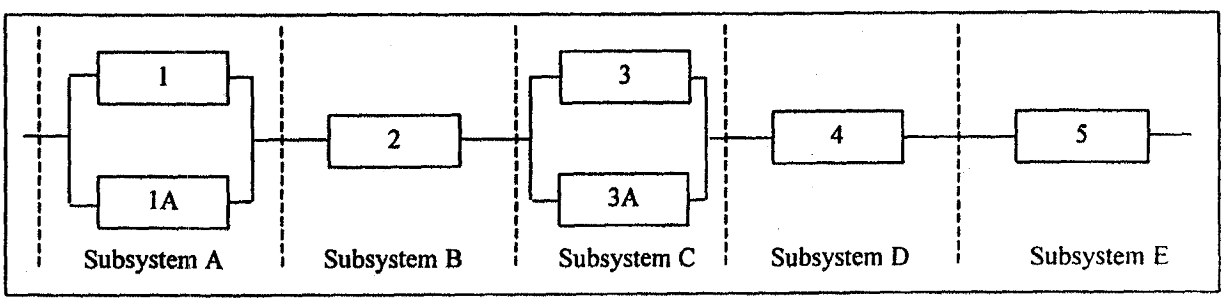

Figure 4-2. Example of a reliability block diagram.

(2) *Fault tree.* figure 4-3 is an example of a fault tree developed for one type of failure in an elevator (passenger box falls free).

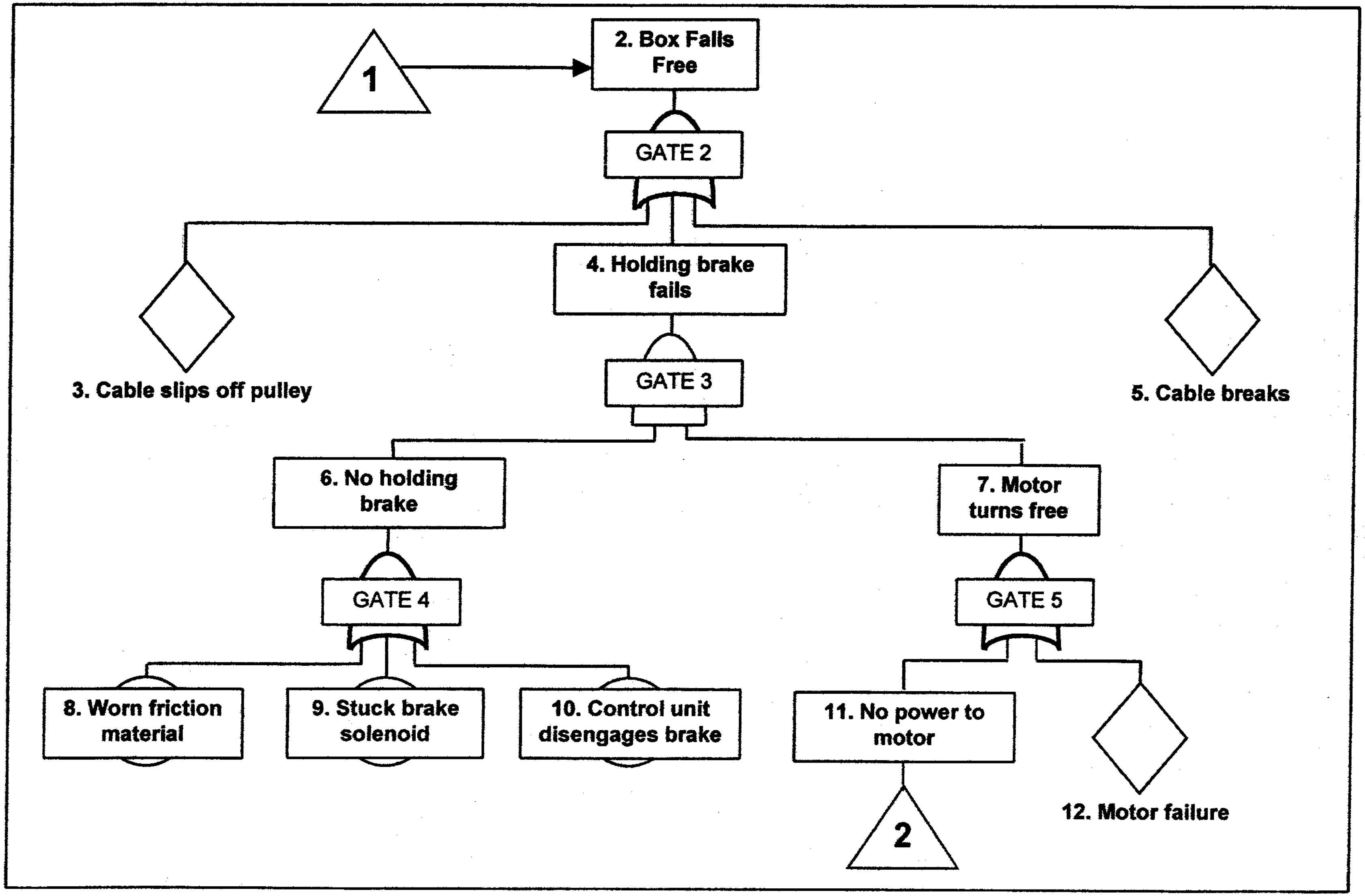

Figure 4-3. Example of a fault tree (from RAC Fault Tree Analysis Application Guide.)

b. *The GO method.* The GO software was originally designed to address the need of availability of nuclear facilities. The GO method, unlike fault tree analysis which focuses on a single system event and uses good/bad elements, is a comprehensive system analysis technique that addresses all system operational modes and is not restricted to two-state elements. GO is not a simulation package but a tool that utilizes the point estimates of component reliabilities to calculate desired system metrics. The GO procedure has been enhanced over the years to incorporate some special modeling considerations, such as system interactions and dependencies, as well as man-machine interactions. Key features of the GO method are listed in table 4-3.

Table 4-3. Key features of the GO method

• Models follow the normal process flow;
• Most model elements have one-to-one correspondence with system elements;
• Models accommodate component and system interactions and dependencies;
• Models are compact and easy to validate;
• Outputs represent all system success and failure states;
• Models can be easily altered and updated;
• Fault sets can be generated without altering the basic model;
• System operational aspects can be incorporated; and
• Numerical errors due to pruning are known and can be controlled.

c. *Single line diagram.* The first step to performing an analysis with GO is to develop the one line drawing that represents the system. The single line diagram provides the analyst the path that must be modeled by GO to accurately represent the physical and logical equipment of the system. Figure 4-4 represents a single line diagram of the IEEE Gold Book Standard Network System.

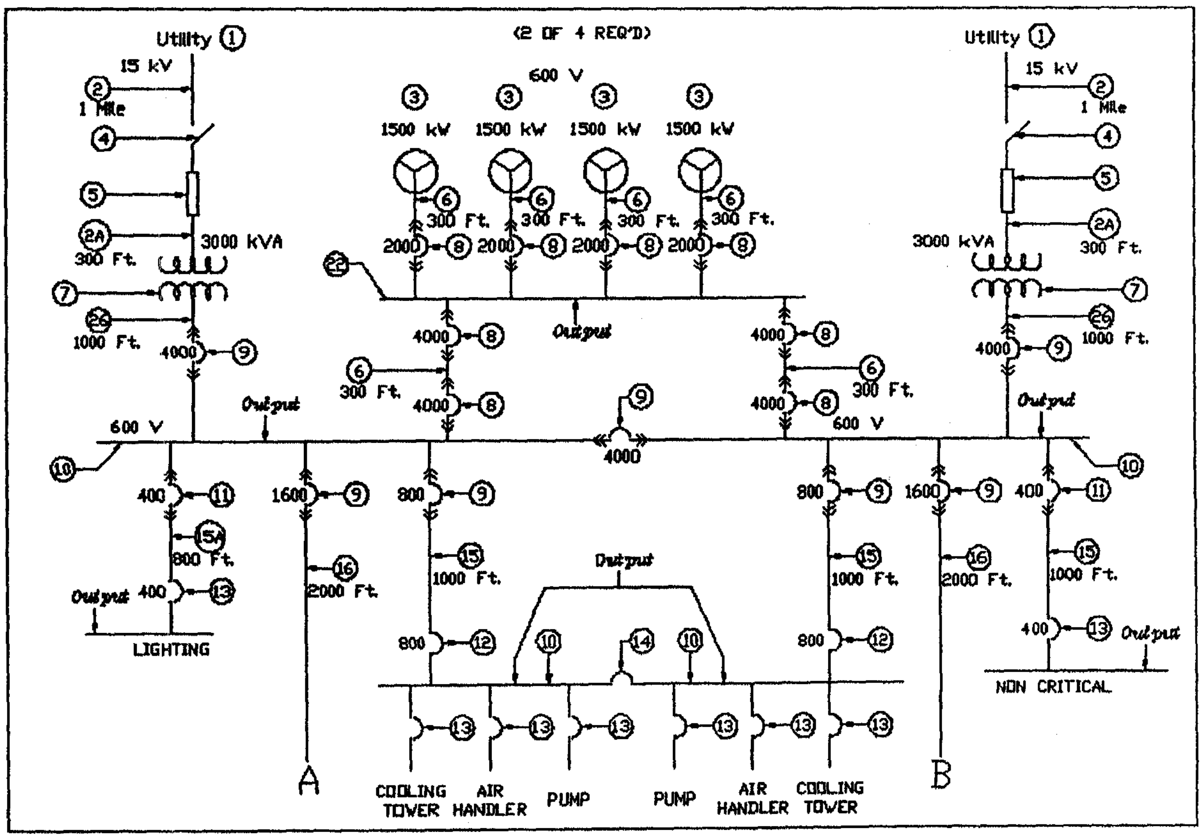

Figure 4-4. Example of a single line diagram (from IEEE Gold Book Standard Network).